

# An Update on US-LHC Accelerator Physics Activities at BNL

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1. Overview
2. Magnet Error Assessment & Compensation Strategy
3. Production Monitoring & Support
4. CERN Compatibility & Software Adaptation
5. Summary

## Budget profiles:

WBS	LAB	Labor [fte-yrs]	Labor [k\$]	Matl. [k\$]	Total [k\$]
1.4.1	BNL	14.0	1,983	0	1,983
1.4	Total	36.2	5,083	176	5,259

Year	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	Total
[fte-yrs]	0.5	2.0	1.6	1.9	2.0	2.0	2.0	2.0	14.0

Section	Title	BNL [fte-yr]
	<b>Design Issues</b>	
4.1.1	Dynamics analysis & simulation	4.3
4.1.2	High Gradient Quadrupoles	1.5
4.1.3	Beam splitting dipoles, D1	0.5
4.1.4	RF section magnets	1.0
4.1.5	Alignment	3.3
4.1.6	Quality review of production magnets	2.8
	<b>Beam Physics Issues</b>	
4.2.4	Software maintenance & development	0.6

- “Labor” and “Materials” are fully loaded with overhead and contingency.
- Travel costs are covered in the Project Management budget.

# 1. Overview

- Production oriented — support US-LHC magnets
  - \* Design stage: (4.1.1, 4.1.2, 4.1.3, 4.1.4)
    - Impact assessment of magnetic & alignment errors
    - Magnet design optimization & compensation  
(end orientation; body-end compensation;  
tuning shim optimization; quench/thermal dependence)
    - Triplet corrector layout & strategy  
(higher order correctors; beam-based; local decoupling)
  - \* Production stage: (4.1.5, 4.1.6)
    - Database to record field & alignment data
    - Routine analysis & review of measurement data
    - QA feedback to magnet builders and surveyors
    - Installation preparation & Sorting
- Compatibility to CERN software and analysis (4.2.4)
  - Benchmarking & occasional cross-check
  - Standard eXchange File (SXF) shards by various codes and labs

- **Scope**
  - Integrated analysis of LHC collision performance
  - US-LHC magnets: HGQ (FNAL) & RF dipoles (BNL)
  - Relevant non US-LHC IR magnets: other HGQ (KEK), IR dipoles D1 (CERN?)
- **Collaboration with other laboratories**
  - Intimate relation with BNL & FNAL Magnet Groups, and with FNAL AP Group
  - In close contact with CERN AP Group and Magnet Groups  
(parameter verification; monthly reports; workshops; visits;  
MTA Group for magnet measurement database structure)
- **The Team**
  - J. Wei, F. Pilat, V. Ptitsin, S. Tepikian (RHIC AP); C.G.. Trahern (RHIC Controls)
- **US Collaborators**
  - R. Talman, N. Malitsky (Cornell); J. Shi (U. Kansas)
- **A “Technology Transfer” — RHIC to US-LHC**
  - Adaptation of analysis method, software tools, and database structure
  - Adaptation of compensation strategy & corrector layout

## 2. Magnet Error Assessment & Compensation Strategy

Figure of Merit: action-kick minimization

$$\left| \frac{\Delta J_{x,y}}{J_{x,y}} \right| = \frac{1}{4\pi\rho} \int \sum_n \beta_{x,y} \left[ (2\beta_{x,y}J)^{1/2} + \frac{\Delta_{sep}}{2} \right]^{n-2} c_n ds < 0.005,$$

$$c_n = \begin{cases} \frac{10^{-4}b_n}{R_0^{n-1}}; & \text{or } \frac{10^{-4}a_n}{R_0^{n-1}}, & \text{(for dipoles)} \\ \left(\frac{G_0}{B_0}\right) \frac{10^{-4}b_n}{R_0^{n-2}}; & \text{or } \left(\frac{G_0}{B_0}\right) \frac{10^{-4}a_n}{R_0^{n-2}}, & \text{(for quadrupoles)} \end{cases}$$

Action-kick sensitivity to D1 errors at collision:

Multipole	$b_2/a_2$	$b_3/a_3$	$b_4/a_4$	$b_5/a_5$	$b_6/a_6$	$b_7/a_7$	$b_8/a_8$	$b_9/a_9$	$b_{10}/a_{10}$	$b_{11}/a_{11}$
$ \Delta J/J  (\times 10^{-3})$	4.08	2.48	1.51	0.93	0.57	0.35	0.21	0.13	0.08	0.05

- 1 unit multipole error;  $\beta^* = 0.5$  m;  $11\sigma$  amplitude
- reference radius defined at  $R_0 = 25$  mm

# Reference D1 Magnetic Errors at Collision ( $R_0 = 2.5$ cm):

Order, $n$	Normal			Skew		
BODY [unit]	$\langle b_n \rangle$	$d(b_n)$	$\sigma(b_n)$	$\langle a_n \rangle$	$d(a_n)$	$\sigma(a_n)$
2	0.1	0.8	0.3	0.6	3.5	1.6
3	-3.3	3.4	1.8	-0.3	0.6	0.2
4	0.0	0.3	0.1	0.0	1.1	0.4
5	0.5	0.8	0.4	-0.1	0.2	0.1
6	-0.1	0.1	0.0	-0.1	0.6	0.2
7	1.1	0.2	0.1	0.0	0.1	0.0
8	0.0	0.0	0.0	0.0	0.2	0.1
9	0.0	0.1	0.1	0.0	0.0	0.0
10	0.1	0.1	0.0	0.0	0.0	0.0
11	-0.6	0.0	0.0	0.0	0.0	0.0
LEAD END [unit-m]	$\langle B_n \rangle$	$d(B_n)$	$\sigma(B_n)$	$\langle A_n \rangle$	$d(A_n)$	$\sigma(A_n)$
2	-0.5	2.3	1.0	-1.4	4.3	1.8
3	22.4	2.9	1.1	-9.9	1.0	0.4
4	0.0	0.7	0.2	0.1	0.8	0.3
5	-0.4	0.7	0.2	2.2	0.3	0.1
7	0.9	0.1	0.1	-0.9	0.1	0.1
RETURN END [unit-m]	$\langle B_n \rangle$	$d(B_n)$	$\sigma(B_n)$	$\langle A_n \rangle$	$d(A_n)$	$\sigma(A_n)$
2	0.2	1.8	0.7	0.9	4.5	1.9
3	6.1	2.7	1.2	0.3	1.0	0.3
4	0.0	0.4	0.2	0.2	0.7	0.3
5	0.0	0.7	0.2	0.0	0.3	0.1
7	0.0	0.1	0.1	0.0	0.1	0.1

- Version 1.0 dated Feb. 4, 1998, based on RHIC arc dipole measurement data

# Reference HGQ Magnetic Errors at Collision ( $R_0 = 1.0$ cm):

Order, $n$	Normal			Skew		
BODY [unit]	$\langle b_n \rangle$	$d(b_n)$	$\sigma(b_n)$	$\langle a_n \rangle$	$d(a_n)$	$\sigma(a_n)$
3	0.	0.2	0.5	0.	0.2	0.5
4	0.	0.09	0.3	0.	0.09	0.3
5	0.	0.04	0.07	0.	0.04	0.07
6	0.	0.02	0.03	0.	0.02	0.03
7	0.	0.01	0.008	0.	0.01	0.008
8	0.	0.004	0.003	0.	0.004	0.003
9	0.	0.002	0.0016	0.	0.002	0.0016
10	0.0003	0.0009	0.0005	0.	0.0009	0.0005
LEAD END [unit-m]	$\langle B_n \rangle$	$d(B_n)$	$\sigma(B_n)$	$\langle A_n \rangle$	$d(A_n)$	$\sigma(A_n)$
2	0.			16.		
6	0.27			0.0083		
10	-0.0013			-0.00046		
RETURN END [unit-m]	$\langle B_n \rangle$	$d(B_n)$	$\sigma(B_n)$	$\langle A_n \rangle$	$d(A_n)$	$\sigma(A_n)$
6	0.046					
10	-0.0013					

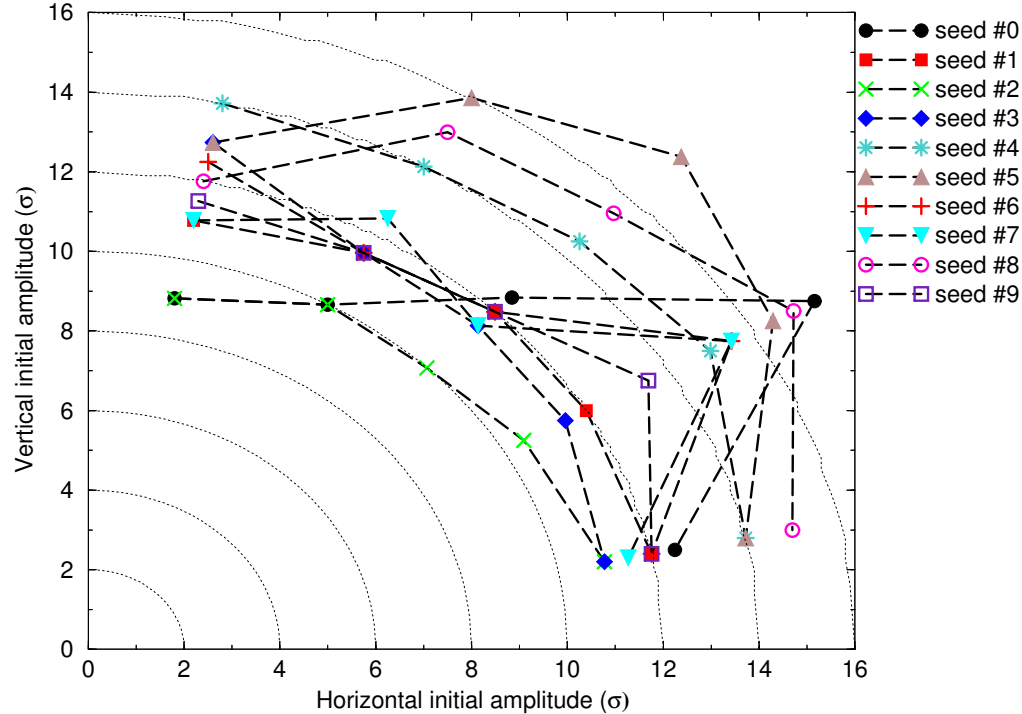
- Version 1.0, based on TD-97-050, G. Sabbi, November 1997



# 6-Dimensional Tracking of HGQ Errors at Collision:

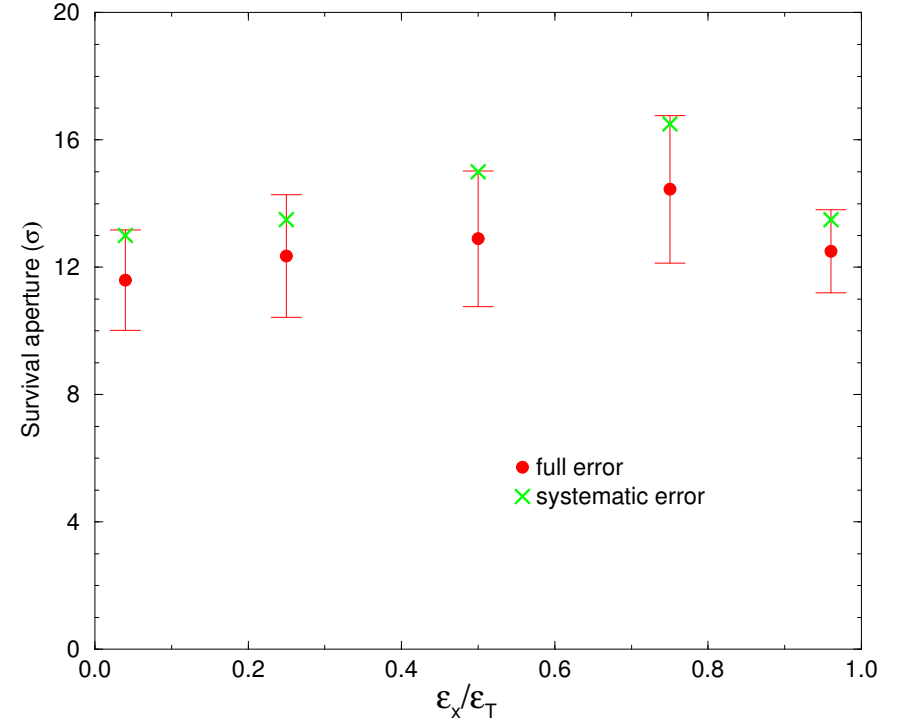
LHC Collision (v.5.0), HGQ

full error,  $\Phi=0$ , 50k turns; (2/19/98)



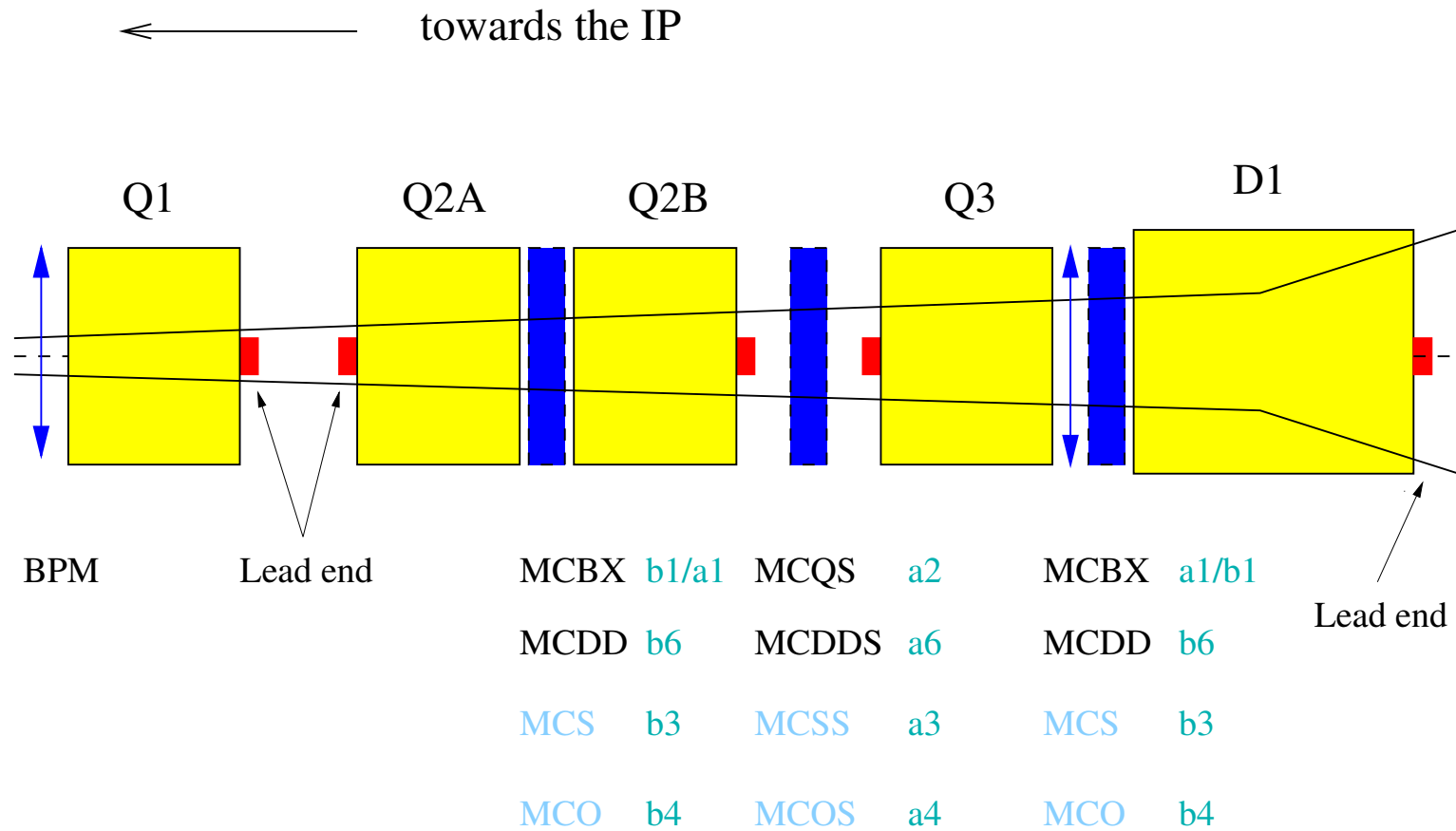
LHC Collision (v.5.0), HGQ

$\Phi=0$ , 50k turns; (2/19/98)

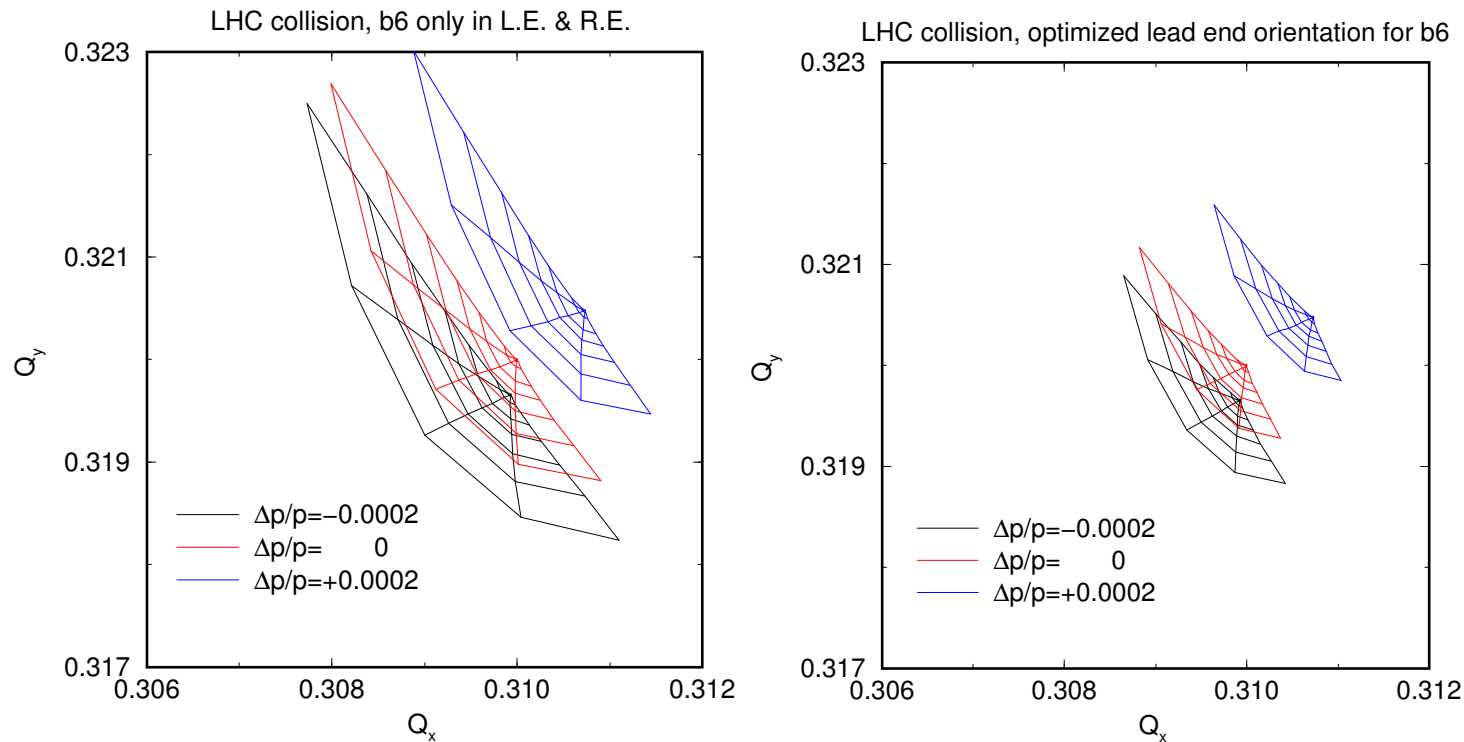


- 50k turn tracking using TEAPOT; zero crossing angle assumed
- mostly caused by random  $a_3/b_3$  and  $a_4/b_4$  error
- $\Rightarrow$  Need IR correction

# Insertion Region Proposed Layout

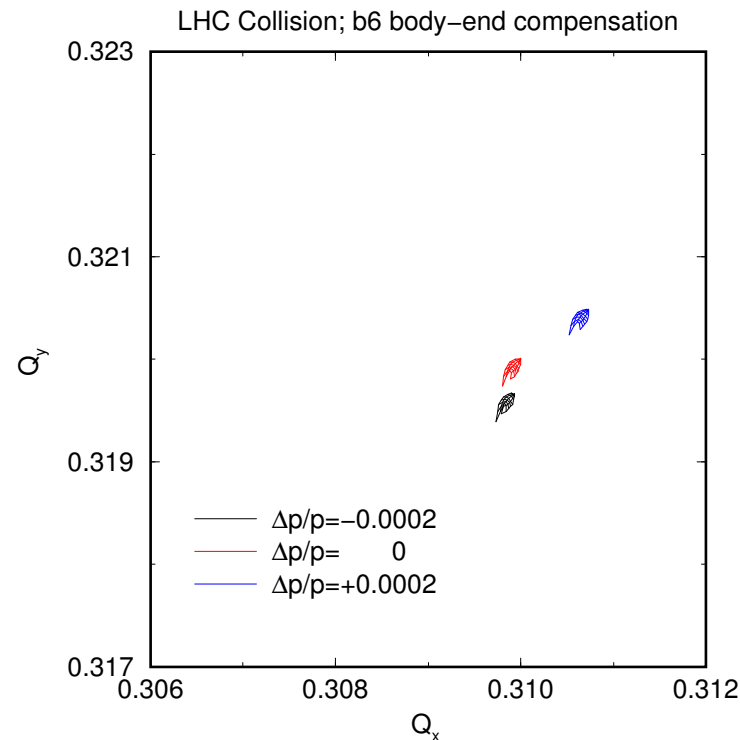


# Tune Footprint Optimization with Magnet Orientation:



- impact of  $b_6$  in HGQ lead ends minimized by F vs. D cancellation
- impact of  $b_3$  in D1 dipole lead end reduced
- works for both beams at low  $\beta^*$

# Body-End Compensation



HGQ:

$$b_6(\text{body}) = -0.10 B_{6L} - 0.23 B_{6R} = -0.6 \text{ (unit)}.$$

- weighted by  $\beta$  function to  $(n/2)$ th power; integrated  $b_6$  compensation over each triplet
- coefficients show proper magnet orientation; optimum for  $\beta^* = 0.5 \text{ m}$  (IP1, IP5)

D1:

$$b_3(\text{body}) = -0.095 B_{3L} - 0.116 B_{3R} = -2.8 \text{ (unit)}.$$

## Tuning Shims

- individually correct each HGQ and D1 after it is constructed and measured
- with 8 slots for shimming, can correct at least 4 body harmonics
- limited by measurement uncertainty
- limited by field variation with quench & thermal cycles

## IR Correctors

- valuable “knobs” for beam-based correction
- useful for large measurement error & quench/thermal dependence
- for each multipole, need 2 correctors per triplet

## RF Section Issues

- persistent  $b_3$  at injection; saturation  $b_3$  at maximum energy
- lack of local correction in RF Section

## Compensation Strategy for HGQ and D1:

Order, $n$	Normal, $b_n$	Skew, $a_n$
1	MCBX	MCBX
2	trim	MCQS
3	S, (MCS [2])	S, (MCSS)
4	B, S, (MCO [2])	S, (MCOS)
5		
6	B+, MCDD [2]	B+, MCDDS
8	B	
10	B	

B: coil cross-section iteration

+: body-ends compensation

S: using tuning shims

MCBX: normal/skew dipole corrector for closed orbit

MCQS: skew quadrupole for decoupling

MCDD, MCDDS: local  $b_6/a_6$  correctors

MCS, MCSS: local  $b_3/a_3$  correctors

MCO, MCOS: local  $b_4/a_4$  correctors

### 3. Production Monitoring & Support

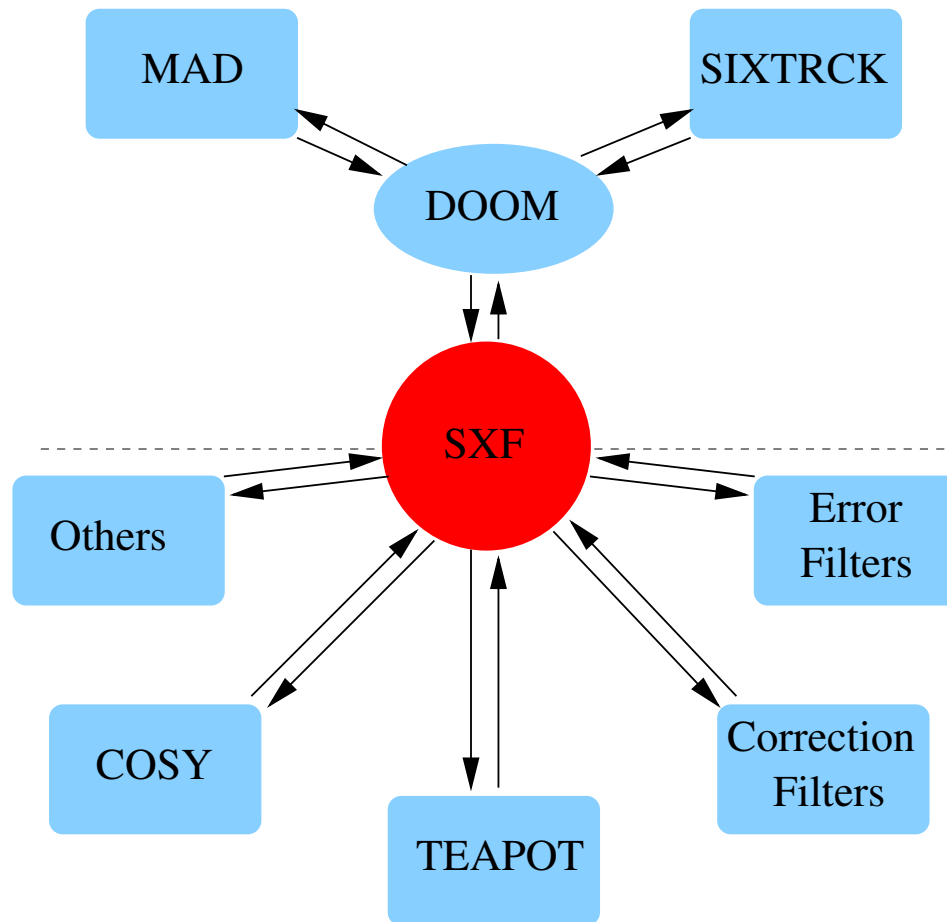
- Review of magnetic field measurement data  
statistics and trends;  
quick feedback to magnet groups
- Review of alignment measurement data  
magnetic field w.r.t. coldmass fiducials;  
quadrupole w.r.t. multi-layer correctors
- Installation support  
magnetic field w.r.t. cryostat fiducials  
sorting
- database structures completed by BNL
- in contact with FNAL measurement group
- in contact with CERN magnet groups
- database/dataflow mini-workshop in June 1998

## Summary of Database Tables for Measurement Data:



## 4. CERN Compatibility & Software Adaptation

- Benchmarking & occasional cross-check
- Standard eXchange Format (SXF) shared by various codes and labs
- UAL-LHC mini-workshop held in February 1998



## 5. Summary

- 2.0 fte/year, to support US-LHC magnet design & construction at all stages
- Work as an integrated part of the program, closely collaborating with magnet groups at BNL & FNAL, AP groups at FNAL a& CERN, and later survey groups at various labs
- Jointly maintain *Reference* field error & misalignment tables (BNL & FNAL)
- Share benchmarked software and a Standard eXchange Format (SXF) as a base for both routine analysis and specialized error compensation (BNL, CERN, FNAL)
- Software workshop (for SXF development) held in February 98; database/dataflow workshop in June 98; joint workshop in 99
- To meet the demand and milestones of the Program